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DETERMINATION OF THE REAL PATHS OF FIREBALLS

By R. A. McINTOSH

THE determination of the real paths of brilliant fireballs* by the collection and discussion of observations made by the general public provides a most fascinating mental exercise, during which the computer often necessarily assumes the role of a detective in his endeavour to ascertain the real meaning of observations concealed in a maze of prolixity and misunderstanding.

The correct interpretation of such reports by an experienced computer of real paths yields data almost as accurate as can be expected where two or three trained meteor observers make simultaneous observations. It is essential, however, that the computer should approach his task with a solid background of practical meteoric observing to obtain the best results. Without this practical experience one is inclined to view the problem in the wrong perspective.

Aspects of the determination of real paths of fireballs have been dealt with at various times. The Newton-Denning method (1, 2 and 3)† requires the use of a celestial globe. The utility of this method in experienced hands is revealed by large numbers of real paths published in England. The use of the stereographic projection also has been advocated (4). Logarithmic methods are available (5). Where only two or three observers are concerned several good methods may be used involving logarithmic calculation (6 and 7) and graphical treatment (2). There is a method

*The word fireball is used throughout as indicating an exceptionally brilliant meteor.

†These numbers are the references at the end of this paper.

specially applicable to photographs, where the end points of the path are not ascertainable (8). In a recent paper formulae are given by which the observed directions from two stations are adjusted through equal angles, furnishing minimum values for the errors of observation, while a least squares method is given for determining heights of fireballs seen at two or more stations (9). There are numerous excellent references in other languages (10).

Most of these papers, however, refer only to special phases of the subject, and are designed generally to cater for the accurate observations made by experienced meteor observers on a prepared base-line. No complete article on the treatment of large numbers of observations made by inexperienced observers has appeared in the English language, yet such observations properly handled are capable of producing data comparable with those obtained from the observations of experienced meteor observers. A meteor worker desirous of taking up the study of real paths of fireballs is faced, as I was, with the initial problems of discovering in widely scattered literature the various papers already published and then selecting for himself the most suitable methods.

The necessity for the statement of a method which has stood the test of practical working, if others are to be encouraged to take up this fascinating and essential side of meteoric astronomy, has led me to prepare this paper. Very little of it, I must confess, is my own. It has been compiled from the published works of many practical computers of real paths, modified or extended to suit conditions as I have found them. As an aid to the tyro and in acknowledgment to those upon whose material I have so freely drawn, an extensive bibliography is included, containing all the worth while matter on the subject that has come under my notice.

Accuracy of Data Obtained.—To illustrate the degree of accuracy obtainable, the late A. King finds (11) for a fireball observed by over 200 people an error of two miles in heights at beginning and ending, an error of four miles in length of path and of five miles in velocity. W. F. Denning, with a large total of real paths to his credit, found from a comparison of 75 cases separately computed by A. S. Herschel and himself (12) mean errors of four miles at beginning, 3½ miles at end point, 3¾ miles in length of path and 3½ miles in velocity. Rejecting ten cases the discordance is

reduced to one mile for each feature. Denning concludes that for a real path really well-observed at two places the error should not exceed two miles. Of course, the errors Denning has quoted above are not probable errors in the true path but represent rather the element of personal selection between the two experienced computers in the data available to them.

Reports from Untrained Observers

Collection of Data.—When exceptional fireballs are reported, such as are likely to have been witnessed over a wide area and to have made an impression on the minds of observers, no time should be lost in requesting observations by medium of the daily press circulating in the area in which the fireball is likely to have been visible. It has been found in New Zealand that requests published in a few large metropolitan dailies bring better results than from similar appeals in a number of small provincial newspapers. A knowledge of the circulation of newspapers and the territory they cover is therefore most important. As an example, in this Dominion a morning paper gives provincial coverage, while its evening contemporary extends only to the suburban limits of the city. Radio broadcasting stations also provide splendid coverage in the more isolated districts, where newspapers do not rapidly penetrate.

The first request for observations should give the public some idea of what is required of them (13). The following is a typical letter often used in this country.

To the Editor,

Sir,—On the night of ..... about 8 p.m. a bright fireball was observed in the ..... district. It was a very brilliant object, lighting up the surrounding countryside. The study of such objects is very useful to scientists n helping to solve many problems concerning our atmosphere and the nature of the meteor itself. The writer therefore would be grateful for reports from any who have witnessed this meteor. The data required are: (1) Exact location of observer; (2) date and time of appearance of meteor; (3) the position of its path in the sky with reference to the stars, by compass bearings, or in relation to terrestrial objects; (4) particulars of any noises which accompanied or followed the meteor; (5) description of the brightness of the object and its trail, and (6) the length of time the meteor (and trail) remained visible.

Signature and address.

As it is most important to get in touch with observers while their memories of the incident are fresh, the New Zealand Meteor Section has established agents in every important city of the Dominion whose duty it is to initiate press campaigns immediately such objects are seen. The scheme has proved highly successful, resulting in more and better data being collected than would have been the case if the task had been left to the computer, perhaps a thousand miles from the track of the fireball.

There is a divergence of opinion as to the best method of dealing with the first reports. It is the practice of the American Meteor Society to send to each observer a detailed questionnaire, covering every point likely to arise in the computation of the real path. The questions asked in this particular list are given, for guidance of those who desire to collect such data themselves.

QUESTIONNAIRE

(1) Name and address. (2) Where were you when you saw the meteor? (3) Hour and minute of appearance, also kind of time used. (4) In what direction did it appear, or in what direction was it first seen? (5) In what direction did it disappear, or was last seen? (6) At what height did it appear (use degrees)? (7) At what height did it disappear (use degrees)? (8) Did it pass *directly* overhead, *i.e.* through the zenith? (9) If not, to which side of the zenith did it go, and how far from it (use degrees)? (10) Did it appear to reach the horizon? (11) What angle did the path of the meteor make with the horizon and in which direction was it then going? (12) If you are familiar with the constellations describe the path of the meteor through the sky with reference to the stars. (13) Did it appear to explode? (14) What was the duration of its flight in seconds? (15) Describe the trail if one was left. (16) What was the duration of the trail in seconds? (17) Did you hear any sound? How long after seeing the meteor was it before you heard this sound? Did you hear an actual explosion? How long after *seeing* the explosion was it before you *heard* it? (18) What colour was the meteor? (19) What was the size of the meteor (compare with Moon, planet or star)? (20) Was more than one body seen before the explosion (if any)? (21) Give names and addresses of others who saw this meteor. A careful explanation of the more difficult points in the list follows as guidance to the inexperienced.

Dr. C. C. Wylie (13) advocates the interviewing of observers on the spot where the fireball was seen. In this he is supported by Dr. H. H. Nininger (14). It is impossible, however, to interview all observers, sometimes numbered in hundreds, and only a selection of the apparently good reports end in a personal interview.

For the amateur meteor worker, lacking the time and funds of the professional, this method is definitely ruled out. The questionnaire, however, covers a wide field and the inherent errors have a way of cancelling themselves out, so that in Dr. Olivier's opinion (15), with which I am in hearty agreement, equally good results can be obtained through the mails by an experienced meteor worker.

I have found that many untrained observers have great difficulty in correctly answering the various points raised by the questionnaire, even if they are not completely dismayed by their first glance at it. Therefore I have discarded this method almost entirely in favour of personal letters, in which I seek to extract the best points from an observer's first report. For example, one person may see the fireball apparently end between two trees on his own property. I fasten on this point and endeavour to get exact bearings and heights of the trees and fireball, not worrying the observer about (say) the beginning point, of which he may be very doubtful. From other observers, according to circumstances, I hope to get equally good information on other features of the phenomenon. In all cases observers are encouraged to give diagrams supplementing their written statements.

Interpretation of Data.—When the press campaign has concluded, and all the good points in the various letters have been established by correspondence, the computer's task has hardly begun. Although his hundred or so correspondents are actuated by the best of intentions, they often find great difficulty in putting their observations into words and describing correctly their various impressions. The questioner himself finds difficulty in getting them to comprehend exactly what is required.

Estimation of the value of a report should be based mainly on the internal evidence of that report, and we can always assume that the person who goes to the trouble of reporting is intelligent and genuinely desirous of helping. Reports should not be rejected just because there is some point which is flagrantly wrong or ridiculous. Each report is a genuine contribution and the computer must endeavour to read between the lines of the actual letter and grasp the message that is hidden there.

Errors Commonly to be Expected.—One must guard against apparently simple descriptions being more or less a product of the

observer's imagination. It is practically impossible for the inexperienced to dissociate themselves from the impression of the fireball's close proximity, and this gives rise to many errors.

An excellent recent article (16) described how six men could observe a fireball under similar circumstances and send in six entirely different reports, each being a true description of his impression of the object. Often an observer will mentally prolong the apparent path to a point where he imagines the fireball actually struck ground, and then he gives that bearing as the end point of the path. Another may visualize the real path as being over objects in the neighbourhood and give his estimate of its direction, often widely differing from its true direction. Then, because the fireball grew rapidly brighter, another observer may believe that it was approaching him and ended quite near. He will often offer to take you to the spot where it landed! But his report is worthless because he allowed imagination free play.

Even diagrams are liable to error. I have encountered the case where beginning and end points are correctly reported, but the written word is supplemented by a drawing into which the observer projects himself, allowing the computer to stand afar off and view him in perspective, and the drawing becomes then nothing but a snare.

Error often arises also from a misconception of what a fireball is. In one case investigated by the writer (17) some observers looked up too late to see the fireball. They did see, however, a thick glowing train, which remained visible for some minutes. As it faded in the reverse direction to the fireball's flight they naturally reported the wrong direction of flight.

The ways in which error can arise are legion. The computer must always be on his guard when handling reports from inexperienced observers. Only by combining numerous observations and delving behind the written word is it possible to detect these errors and make the best use of them.

Tabulation of Data.—The questionnaire has one great advantage over the ordinary letter—the replies are tabulated and are in readily accessible form. Where the computer relies, as I do, on the method of personal correspondence, it becomes essential to lay out the data in tabular form. Any required matter can then be found

instantly, without the necessity of reading through pages of description. But in such cases, and even with the questionnaire, it is desirable to weigh each point in the data according to its value. For example, a reference point that is fixed by the stars or terrestrial objects can be given far greater weight than one depending on little more than a guess. The would-be computer is advised to study, in this connection, Dr. Wylie's system of classifying the data (18). Dr. Wylie classes the observations under four headings, depending on (1) the familiarity of the observer's surroundings, (2) how the angles were measured, (3) the availability or otherwise of good terrestrial landmarks, (4) the intelligence of the observer, graded according to occupation. The time elapsing between the making of the observation and the recording thereof also is indicated. In my opinion the system would be most valuable if it were used to indicate the value of each item of the report, because one rarely receives a report the whole of which can be assigned one weight.

Determination of Projected Path of Fireball

Points of Special Importance.—In almost every real path investigated it will be found that some of the observers are especially favourably placed in relation to the fireball's true path. If the fireball appears stationary to the observer he is situated at its earth point. If it appears to rise vertically in the sky the observer is below its true path, being between the earth point and the projected end point if the object does not reach his zenith, and between the projected beginning and end points if it does pass his zenith. If the fireball falls vertically the observer is in the plane of its path but beyond the earth point or the beginning point. Observations showing vertical inclinations are therefore of particular value. It must be pointed out, however, that the description "the fireball fell straight down" generally can be translated as meaning that it fell and that its path was a straight line. Only with the additional words "inclining neither to right nor left" or other evidence is it possible to accept such descriptions with certainty. Similarly stations from which the fireball was seen overhead should be useful in gaining a first impression of its true path. Unfortunately "overhead" to the general public is a rather wide area,

and observers 20 miles or more distant from the projected path will often report that the fireball passed directly overhead. The area where the shock wave is heard also provides a good indication of the path and end point of a fireball, but this will be dealt with later.

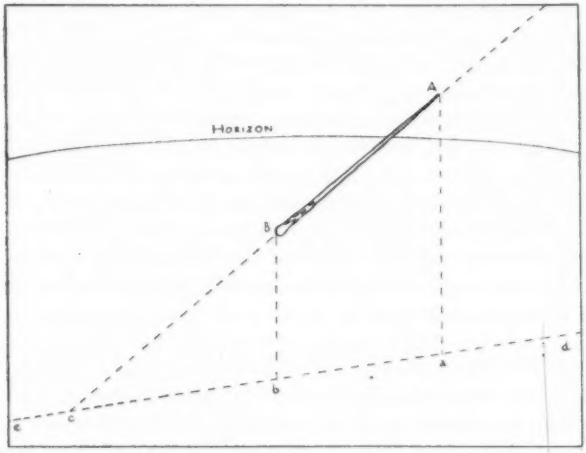

Figure 1.—The Path of a Fireball. *AB* represents the true path of a fireball, and *C* the earth-point. The vertical projection of the true path onto the earth's surface is *ab*. The apparent path, for observers situated at various places on the earth will then be as follows:

Observer	*Fireball's path*
at *a*	begins at zenith, falls vertically.
at *b*	rises vertically, ends at zenith.
at *c*	appears stationary.
on *da*	falls vertically.
on *ab*	rises and falls vertically, crosses zenith.
on *bc*	rises vertically.
on *ce*	falls vertically.

First Approximation to Projected Path.—On an ordnance map of the district, or any map of fairly large scale, the lines of sight of beginning and end points must be projected from the positions occupied by each observer. It is advisable to deal first with the end point, as being probably the better determined of the two

points, before marking in the sight lines concerned with the beginning point. In cases where the fall is nearly vertical it is essential to use a separate map for the beginning point, as otherwise there would be overlapping and confusion between the two sets of lines.

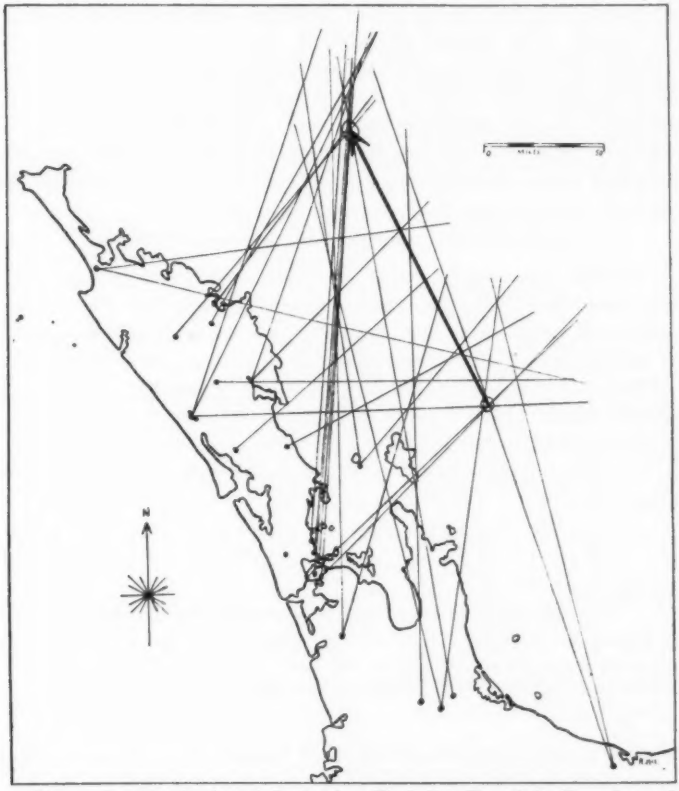

Figure 2.—The Projected Path of a Fireball. The sight lines from the various stations intersect near the projected beginning and end points of the Fireball's path, the amount of spread revealing the accuracy of the observations.

An inspection of the projected sight lines will reveal a spot

where the lines intersect after the manner of projected meteor paths at the radiant. The amount of spread will be a good indication of the accuracy of the data. In the accompanying illustration the sight lines concerning a New Zealand fireball of 1934 May 24 are shown. The fireball was seen in bright twilight, when only Jupiter, Spica and the moon were visible, and was for practical purposes a daylight object. I myself observed this object, and as both ends of my apparent path were well determined, this has somewhat influenced me in determining the exact position of the projected path. Considering that practically all the observations

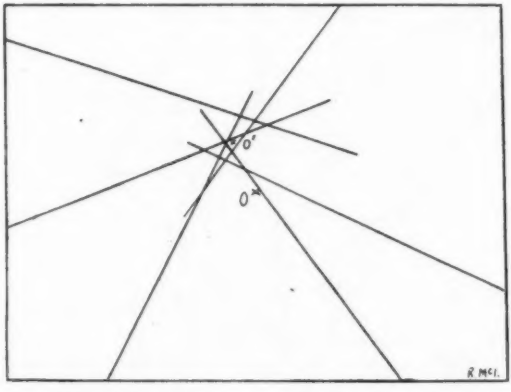

Figure 3.—Magnified Projections of Sight Lines. Dr. W. J. Fisher's method of accurately determining a projected point on a Fireball's path. 0 is the arbitrary origin and 0^1 the finally adopted point.

were based on terrestrial landmarks, I consider that the agreement between the various observations is particularly good.

When the weighted "centre of gravity" of the sight lines is determined we have the projected end (or beginning) point of the fireball. In cases where the data are poor our computation may have to rest on a visual inspection of the intersections, but in most cases it is desirable to carry this portion of the computations a stage further.

Final Determination of Projected Path

Analysis of Sight Lines.—The following method is due to the late Dr. W. J. Fisher (19). Take the already-determined end point as an arbitrary origin. Its accuracy is not important, so long as it is near the true path. On squared paper with a convenient scale (Fisher used 1′ = 2mm) the arbitrary origin is placed at the centre, the plane of the paper being assumed tangent to the sphere at that point. The sight lines of the various observers from the deduced azimuths at their stations are plotted across the sheet by bearing and length of a normal to sight line, and the true projection of the end point can then be more accurately determined on the larger scale.

The trigonometry required is simplified by the fact that observer and object are not likely to be more than 5 degrees apart, the natural inaccuracy of the observations renders the flattening of the earth unimportant and an average value of the radius will serve for the purpose. In Figure 4a $\angle P$ is the difference in longitude of the observer's station (latitude ϕ_1 at vertex Z_1) and the arbitrary origin (latitude ϕ_2 at vertex Z_2). Then, taking small angles or arcs as equal to their sines, the distance γ is found from

$\gamma^2 = (\phi_1 - \phi_2)^2 [1 + \cos \phi_1 \cos \phi_2 \, P^2 / (\phi_1 - \phi_2)^2]$ very nearly,

and $\sin Z_1 = \cos \phi_2 \, P/\gamma$

$\sin Z_2 = \cos \phi_1 \, P/\gamma$.

The bearing of the fireball being $PZ_1M = Z'$, the normal p from the origin Z_2 on the line of sight Z_1M is given by

$p = \gamma \sin (Z' - Z_1)$ nearly.

This is drawn from vertex Z_2 in the direction given by assuming the small triangle Z_1Z_2M a plane triangle, whence the bearing of M from Z_2, taken with the proper sign, is $90° - (Z' - Z_1) + Z_2$ nearly.

This solution fails when observer and origin are in nearly the same latitude, and the following method is then employed:—

In Figure 4b, $\angle P$ is the difference in longitude between observer (Z_1) and origin O, Z_1Z_2M is the line of sight to the meteor, ϕ_2 is the latitude of the point Z_2 where this line of sight cuts the meridian of O. On PO cut off an arc equal to $90° - \phi_1$, draw the base

Z′Z″ of the isosceles triangle, and bisect P, forming equal right-angled triangle. Then

$$\cot Z' = \tan \tfrac{1}{2}P \sin \phi_1$$

or, in the practical case, Z′ being little smaller than 90°

$$90° - Z' = \tfrac{1}{2}P \sin \phi_1 \text{ nearly,}$$

The base arc $Z'Z'' = P \cos \phi_1$ nearly, and

$$Z_2 = 180° - (Z_1 + P \sin \phi_1), \text{ nearly.}$$

Whence $\phi_1 - \phi_2 = P \cos \phi_1 \tan (Z_1 - Z') [1 + \tfrac{1}{2} P \sin \phi_1 \cot Z_2]$

The normal OM $= (\phi_2 - \phi_0) \sin Z_2$, in which ϕ_0 is the latitude of the origin O, and it is drawn from O in the direction given by $\pm (90° - Z_2)$.

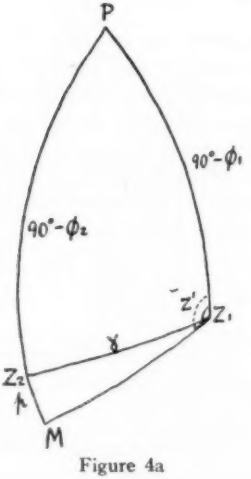

Figure 4a

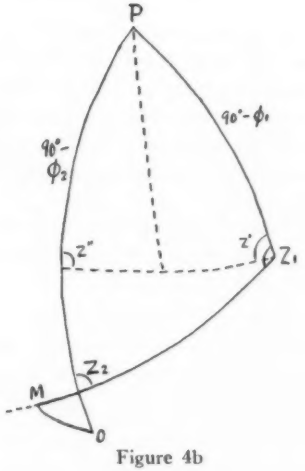

Figure 4b

Having plotted the various sight lines for the selected point the projection of this point on the ground is found by measuring the co-ordinates of the intersections, weighted according to judgment, and finding the weighted means. These give differences of latitude and longitude with regard to the arbitrary origin, and so latitude and longitude of the projected point.

Projected Length of Path.—This can readily be determined by the formula used above for distance of observer from origin.

Let B′ E′ be the projected path length, B′ (λ_1, ϕ_1) and E′ (λ_2, ϕ_2) the beginning and end points (projected) of the meteor. Then

$$(B'\ E')^2 = (\phi_1 - \phi_2)^2 \left[1 + \cos \phi_1 \cos \phi_2 \frac{(\lambda_1 - \lambda_2)^2}{(\phi_1 - \phi_2)^2}\right] \text{ nearly, while}$$

the azimuth of the fireball's path is given by

$$\sin \text{azimuth} = \cos \phi_2 \frac{(\lambda_1 - \lambda_2)}{B'\ E'} .$$

The true path length cannot be determined until the slope of the fireball's path has been found.

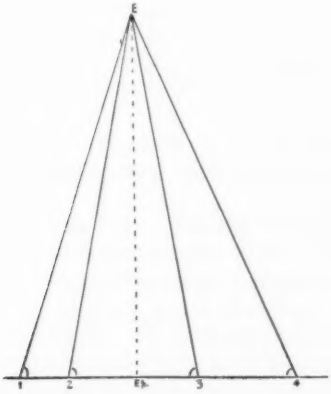

Figure 5.—How the True Path is Determined. The sight lines from the various observers must intersect in the atmosphere just as the projected sight lines must intersect on the map.

Height of True Path.—When the projected beginning and end points of the fireball's path have been determined by either of the methods described, the next step is to determine the heights of these points above the earth's surface.

Correction of Observed Altitudes. (*a*) *Curvature of Earth.*—Owing to the curvature of the earth's surface it is necessary to increase all the observed altitudes by 0.0145° × distance in miles from meteor to observer.

(*b*) *Refraction.*—Where the fireball at its end point closely

approaches the observer's horizon it will be necessary to make due allowance for refraction, if the observations are at all precise. It will generally be sufficient to use tables of mean refraction, such as Bessel's which are readily available.

Real Heights.—Taking the observed altitudes, corrected as above, heights can be determined from the formula

$$H = d \tan h$$

where H is the height, d the distance of the observer from a point on the fireball's path, (projected), and h the corrected altitude.

The following formula may also be used;

$$H = d \tan h' + \frac{d^2}{2R}$$

where R is the radius of the earth in miles, h′ is the observed altitude corrected for refraction, but not for curvature and $d^2/2R$ is a curvature term.

The above formula is not exact, but will usually suffice since errors of observations are large, with a tendency to exaggerate the angular altitudes.

Errors in Estimated Altitudes.—In cases where observers have no fixed reference points and are asked to estimate angles, such estimations are liable to considerable error. Dr. P. M. Millman (20) found from experiments that there is a constant tendency to over-estimate altitudes by 8° or 9°. The mean probable error for an individual was between 4° and 5° and was greater for the higher altitudes. "It would seem," he said, "that an estimate of altitude made without reference to other objects in the sky should generally be reduced by about 8° and considered to have a probable error in the neighbourhood of 5°." This was later confirmed by Miss Patterson (21), when a mean error of 8° ± 6° was found.

Slope of Path.—In Figure 6 let B and E be the beginning and end points of the fireball's path and B′ E′ their projections on the earth's surface. E′T, being tangent to the earth's surface at E′, is the horizon at that point. Draw E′C parallel to EB. Then in the right-angled triangle E′B′C the angle E′B′C is a right-angle (nearly), E′B′ is the projected path length, and $B'C = H_b - H_e$.

(H_b = height at beginning, H_e = height at end)

$$\tan CE'B' = B'C/E'B'$$

This is the angle contained between the slope of the fireball's path and the chord between B′ and E′, and must be corrected for the curvature of the earth's surface. The angular dip B′T is 0.0145° × projected path length.

The true slope at E of the fireball's trajectory then becomes

$$\text{angle CE'T} = \text{angle CE'B'} - \text{angle TE'B'}.$$

The true path length, assuming EE′ and BB′ to be parallel, which is not exactly correct, is

$$\text{P (true)} = \text{CB'}/\sin \text{CE'B'} \text{ (nearly)}.$$

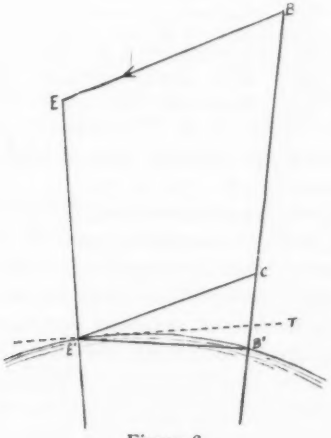

Figure 6

Earth Point.—If a fireball comes very low in the atmosphere before disappearing there is a possibility that meteoritic fragments may be recovered. It is therefore generally desirable to indicate the earth point, or the point where the fireball would have struck if its path had been sufficiently prolonged.

For small angles the chord may be taken as equal to the arc. Then

$$\text{projected length, E' to earth point} = H_e \times \cot i$$

and

$$\text{true length, E to earth Point} = H_e / \sin i$$

Curvature of the horizon must be taken into account when the fireball ends high in the atmosphere and has very nearly a horizontal path. This can be done within the accuracy of the observations by the construction of a further right-angled triangle in which the dip of the horizon and the slope of path are known. The following table shows the excess of the actual projected length, E′ to earth point over the length as computed above:—

Length of Line End Point to Earth Point	Slope of Fireball's Path to Horizontal								
	10°	20°	30°	40°	50°	60°	70°	80°	90°
69 miles	5.9	2.8	1.7	1.2	0.8	0.6	0.3	0.2	0.0
138	13.8	6.6	4.2	3.0	2.0	1.4	0.9	0.4	0.0
207	28.6	14.0	8.7	6.0	4.3	3.2	1.9	0.9	0.0
276	54.2	26.3	16.5	11.5	8.0	5.5	3.5	1.7	0.0

This reveals that the formula will not often be insufficient for its purpose.

True Inclination from Observed Inclination.—The end point of a fireball's path is for a number of reasons generally the best-determined feature. Often it is found in practice that the beginning point is very poorly determined, owing to the various observers first noticing the fireball in different stages of its flight. But although the observers did not succeed in fixing the point of beginning in most cases the slope of the fireball's fall through the sky is described or drawn, or can be easily deduced. Dr. Fisher has used the following formula to correct observed inclinations for perspective:—

$$\tan I = \tan i \sin A$$

where I is the true inclination, i the observed slope and A is the difference in azimuth at the lowest point of the path between the meteor's projected path and the sight line from the observer. This is in error in that it assumes the observer to be on a plane level with the lowest point of the path. It could be remedied, when necessary, by finding for each observer the point where the fireball's path produced would have reached the horizon and determining the azimuth from that point.

Velocity of Fireball.—The observed velocity depends on the

length of the true path and the duration of visibility. Two factors tend to upset the reliability of deduced velocities. Fireballs burst upon the observers while they are preoccupied with their daily tasks, making the point of apparition much more uncertain than the other data, and this of course directly affects the length of path. It has been suggested (22) that in general path lengths are reported too long. My own opinion is that, owing to the unexpected nature of the phenomenon, path lengths tend to be reported shorter than in reality, unless the observers let imagination run riot and mentally prolong the path backwards, which the computer should be able to detect.

If the fixing of the point of apparition is at times doubtful, how much worse is the situation when we come to examine the reported durations upon which the velocity depends! Has anyone, upon seeing the blazing magnificence of a fireball with all its concomitant phenomena, thought to count seconds, or even to recite some verse by which its duration could be estimated later? I have been observing meteors for some 17 years, but have not yet schooled myself to do this. It is not surprising therefore that in the many hundreds of reports from the general public that I have handled no one has ever counted seconds during the flight of a fireball.

B. Boyd (23) has experimented by the unexpected flashing of lights, asking observers to estimate the duration of visibility. Discounting wild estimates, a maximum error of 32% and a mean error of 23% were found in the estimates. When observers were asked to re-enact their movements the error fell to 18%. Unfortunately the error becomes larger for the larger intervals, such as are experienced with the average fireball.

The velocity of any particular fireball may be found by dividing the true path length by the average of the reported durations of visibility (again discounting wild guesses).

This will be the apparent geocentric velocity, increased by the earth's attraction on the meteor. The unperturbed geocentric velocity can be determined by the following table (24), where ΔV must be subtracted from the observed value of the geocentric velocity, V_p:—

CORRECTION FOR EARTH'S ATTRACTION

Velocity between 7½ and 16 miles a second

Vp	ΔV	Vp	ΔV	Vp	ΔV
7½ mls.	4.7 mls.	11 mls.	2.5 mls.	15 mls.	1.7 mls.
8	4.0	12	2.2	16	1.6
9	3.3	13	2.0		
10	2.8	14	1.8		

Velocity between 14 and 110 miles a second

Vp	ΔV	Vp	ΔV	Vp	ΔV
13.7 mls.		18.7 mls.		31.3 mls.	
14.0	1.9 mls.	19.0	1.3 mls.	34.0	0.75 mls.
14.5	1.8	20.5	1.25	37.3	0.7
15.0	1.75	21.6	1.2	41.0	0.6
15.4	1.7	22.7	1.1	46.0	0.55
16.0	1.6	24.9	1.05	52.2	0.5
16.6	1.55	25.5	1.0	60.3	0.45
17.2	1.5	27.2	0.95	70.8	0.4
17.9	1.45	29.1	0.9	87.0	0.3
18.7	1.4	31.3	0.8	110.0	0.25

The heliocentric velocity can be determined from the formula

$$M^2 = E^2 + V^2 - 2VE \cos e$$

where M is the heliocentric velocity, V the unperturbed velocity (geocentric), E the earth's orbital velocity and e the apparent elongation of the radiant from the apex of the earth's way.

To determine the unperturbed geocentric velocity of a fireball, for a given heliocentric velocity Dr. M. Davidson's formula can be used (25):

$$V = \frac{\sin e'}{\sin e} M$$

where e′ is the true elongation of the radiant from the apex of the earth's way. If the parabolic heliocentric velocity is used, $M = \sqrt{2}\ E_c$ where E_c is the velocity in a circular orbit at the corresponding distance from the sun (approximately $E_c = E = 18.5$ miles per second.)

When it is desired to calculate the orbit of any fireball the

method will be found fully described by Dr. Davidson (25) and Dr. C. P. Olivier (26).

The Radiant Point.—Although it would be possible to determine the radiant as is done in meteor observing, by producing backwards the various observed paths until they meet in a common point on the celestial sphere, it is more convenient to determine this point from the known slope and azimuth of the path. At the point directly below the end point of the fireball the azimuth and inclination of its path give the hour angle and altitude of the radiant as seen from this point. These co-ordinates can be transformed into right ascension and declination by the usual formulae (see 25, 26). The various corrections it may be found necessary to apply to the radiant, notably zenith attraction and diurnal aberration, will also be found in the articles quoted.

Other Features of Fireballs

Remarkable Trains.—The fireballs which come under the notice of the general public almost invariably are accompanied by luminous trains, in some cases enduring for many minutes after the meteor has faded out. Where it is known that such a train has accompanied a fireball the computer should pay special attention to this feature, not only in his initial press campaign but also in his subsequent questions.

Meteoric trains, if they endure for any length of time, generally show a rapid drift in the sky and deformations in shape, arising from wind currents in the upper atmosphere, whose strength and direction thereby can be determined. There is sometimes a change in height of the train, showing the presence of other than lateral currents.

Professor Trowbridge, who made such an extensive study of meteoric trains, has found that day and night trains occur at different heights, the day trains lying between 25 and 40 miles and the night trains between 43 and 64 miles, thereby coinciding with the varying level of the ionosphere. Day trains are not luminous, but appear like smoke or cloud, possibly arising from the reflection of sunlight from the meteoric dust composing them. Trowbridge also has found that above 50 miles elevation meteoric trains mostly

move toward the east, while below that height they generally tend to move toward the west, often with great velocities.

When a long-enduring train is left by a fireball and observers report the position of this in addition to the usual data a valuable check on the accuracy of the real path is available, since the determination of the heights of both ends of the train give two additional points on the fireball's path, and all four points should lie on a straight line through the atmosphere (17).

Sounds from Fireballs.—A sharp detonation, or series of detonations, followed by a rumble or roar, are sometimes heard shortly after the passage of a fireball, the time interval depending upon the distance of the observer from the nearest point of the fireball's path. Such noises do not arise from an actual bursting or disruption of the meteor but from a shock wave generated by the body in its rapid flight through the atmosphere. Any object moving faster than the velocity of sound will create such ballistic waves.

It is common knowledge nowadays that the warm ozone layer plays the role of reflecting back to the earth noises generated below the layer. Above, the layer would have the opposite effect, reflecting noise away from us. A meteor therefore must fall below the level of the ozone layer (about 34 miles) before detonations can be heard from it.

These detonations are very useful to the computer when the first observations come in, because the end point can be determined approximately from the places where detonations were audible. If precise timing were available of the interval between the passage of the meteor and the occurrence of the sound an indication of the temperature of the air traversed would be provided (27 and 28), because the velocity of sound depends on the temperature of the air, being 1090 feet a second at 32° Fahr. If the air is warmer than that the velocity of propagation will be greater. It must not be overlooked, in this connection, that wind has its effect on the velocity of sound. In practice, however, no one has yet succeeded in timing the interval sight-sound so accurately as to provide reliable data on temperatures.

Detonations are most intense immediately below the end point of the fireball and may be heard normally up to a distance of about 50 miles. A zone of silence is then encountered, but beyond a

distance of 90 miles a zone of abnormal audibility occurs in cases where the fireball descends to a height of 21 miles or less above the ground.

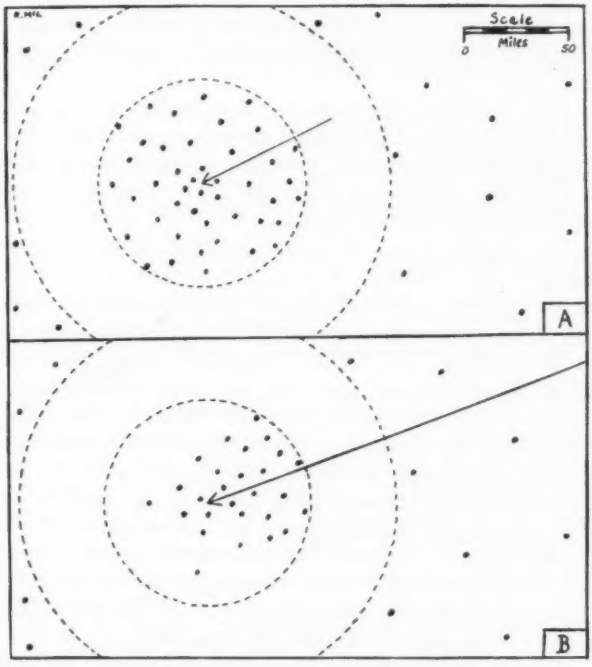

Figure 7.—Audibility of Detonations. Hypothetical stations reporting detonations are indicated by dots. The circles reveal the zones of audibility and silence.
In A the meteor falls almost vertically and the detonations are heard equally well in all directions. In B the fall is nearly horizontal and the noises are heard mostly near and under its trajectory. The outer zone of abnormal audibility is little affected by the slope of the path.

Dr. Wylie has treated the subject of detonations very fully (29). Persons near the terminal point nearly always report the first detonation from about the direction in which the fireball dis-

appeared. The crashing or roaring which follows appears to retreat along the path of the fireball and fades out in the distance in the general direction of the point where the object was first seen. Persons farther back along the path usually report the first blast from the general direction of the nearest point on the path and occasionally hear the rumble travelling in both directions from this point.

If a fireball falls at a low angle to the horizontal the area within which detonations are heard usually spreads out fanwise, back and to each side of the terminal point, being reported for a considerable distance to each side of the path but only for a short distance beyond the point of disappearance. If the fall is nearly vertical detonations may be heard in every direction from the point of termination.

Accuracy of Data.—The accuracy of the real path finally deduced does not depend upon the accuracy of the computations but upon that of the original data. There are places where the formulae themselves are not strictly accurate, but they suffice considering the nature of the reports likely to be received. The computer must always bear in mind, then, that these computations are likely to be approximate, and his finally determined real path should indicate for the benefit of others who may have occasion to use his published data the probable errors to be expected, which can be estimated only by the computer himself from the spread of the data.

Various computers have their own methods of presenting their results, and their work should be studied by anyone embarking on this type of computation for the first time (30). Dr. Fisher has used a probable error based on one-fourth the spread of the data, while the Meteor Section of the British Astronomical Association (31) now shows the total spread between observers. My practice is to show the error as one-fourth the spread of the data, indicating in parentheses the number of observations used in determining each point.

The necessity for practical experience in the observation of meteors has been stressed by all who understand the problems to be encountered in computing real paths. Arbitrary decisions as to the acceptance or rejection of material, the modification of data from the computer's interpretation of the written word, the weight-

ing of the data finally accepted and used, are all matters on which no rules of procedure can be laid down, but must depend mainly on the experience and good sense of the computer.

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HORIZONTAL PENDULUM MOVEMENTS IN RELATION TO LATITUDE VARIATION

By F. Napier Denison

IN the autumn of 1898 a Milne (old type) seismograph was installed here, and was in continuous operation to the close of 1922, when both E-W and N-S instruments of the Milne-Shaw type were started at the new Gonzales Heights Observatory.

Apart from measuring the shorter period movements, such as earthquakes and tremors, the writer became deeply interested in observing certain curious "wanderings" of the E-W pendulum, some lasting for days, and sufficient to necessitate adjusting the levelling screw in order to keep the free end of the pendulum near the centre of the paper.

Thinking these might be due to changes of atmospheric pressure and perhaps other causes, the writer began keeping a continuous record of these movements from January 1, 1899, by measuring the exact position of the free end of the boom each day at noon, and correcting for certain levelling adjustments when necessary from time to time.

A daily curve from these movements was plotted for the years 1899 and 1900, and formed material for a paper read in 1901 before the Royal Meteorological Society, London,[1] and in the autumn of that year the writer personally presented further data at the B.A.A.S. Meeting held at Glasgow. At that time Sir George Darwin advised me to continue the study of the E-W pendulum movements, and to install another instrument of similar type but to swing in the N-S direction.

The daily E-W pendulum movements now form a continuous series of observations from January 1, 1899, to December 31, 1922, and from January 1, 1927, to the present time.

In 1907 the writer constructed a N-S instrument similar to the E-W type, and has obtained from it a continuous daily record of the slow earth movements from September 1, 1908, to September 30,

[1] "The Seismograph as a Sensitive Barometer."

1912. This instrument was installed in the basement of the Victoria Post Office building, and later was moved to the Gonzales Observatory where daily records were started on January 1, 1915, and continue to the present time.

Results from these interesting pendulum movements have formed the subject of several published papers,[2, 3] and in 1911 the writer personally presented a paper on the subject at the International Seismological Congress held at Manchester, England.[4]

In 1913 a fuller account of this work was presented at the annual meeting of the Seismological Society of America, and in January, 1938, the above Society will publish further data by the writer, which will bring the results up to the end of 1936.

In the paper recently forwarded to the Seismological Society, the writer showed curves for the monthly mean values derived from the E-W pendulum movements from 1913 forward to 1936, and from the N-S instrument from 1915 to 1936, (less the four years from 1923 to 1926 when both instruments were not in operation). From these curves it was clearly shown, that in the case of the E-W pendulum the annual extreme easterly movement, though occurring in the spring, summer or autumn months, did not agree with the warmest month, nor did the extreme westerly movements occur during the coldest month of each year. These curves tend to prove that the seasonal temperature extremes are not the primary cause of these variations.

Among the various phenomena studied in connection with these pendulum movements, the latitude variation as observed at Ukiah, California, was taken up. The relationship between these is shown in a marked degree in the following annual curves (Fig. 1) which extend from 1900 to 1922 for the Ukiah latitude variation, and from 1899 to 1922 for the Victoria E-W pendulum. The annual N-S pendulum movements are also shown from 1909 to 1911 and from 1915 to 1922. Owing to the break in the pendulum observations (1923 to 1926 inclusive), and the International latitude variation

[2]"The effect of Atmospheric Pressure upon the Earth's Surface", *Jour. R.A.S.C.*, vol. 2, p. 293, 261, 1908.

[3]The same subject, read at B.A.A.S. Meeting at Winnipeg, Man., 1909.

[4]"Horizontal Pendulum Movements in Relation to Certain Phenomena."

observations being published only to 1930, an extension of the above curves must await further published results for the Ukiah station.

In comparing the two upper curves we find there is a marked secular eastward movement of the pendulum extending from 1900 to 1922, and during the same period, there is a slight increase in the Ukiah latitude readings.

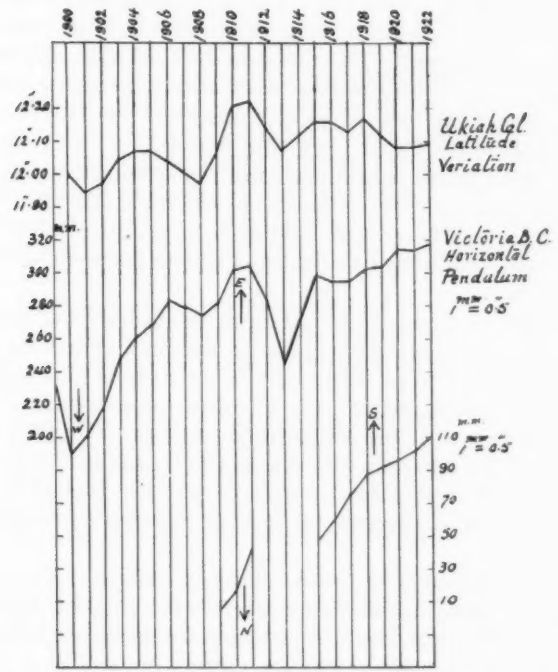

Figure 1.—Curves showing the relation between latitude variation at Ukiah, Cal., and pendulum movements at Victoria, B.C.

Taking the annual results there appears a marked correlation in most years between these curves, and particularly from 1906 to 1918, which suggests there may be some relationship between these pendulum movements recorded at Victoria and slight variations in the

latitude at Ukiah, California. It is surprising that these curves should parallel one another to such an extent, when we consider that the pendulum curve has not been corrected for deviations due to extreme heat in summer or cold in winter, and also the distance between Victoria and Ukiah must enter into this problem.

In connection with the above curves it is interesting to note that the N-S pendulum records show a marked secular movement to the southward, which gives a resultant secular direction for both instruments to the southeast. This tilting to the southward may indicate a rising of this British Columbia coast area as compared with that extending to California, as already suggested by Dr. Gutenberg after a study of the Pacific Coast tidal records.[5]

The writer would suggest that these pendulum movements are to a certain extent under the influence of earth tides, and when further studied these may throw some light upon some of the latitude variation problems now being investigated in various parts of the scientific world.

In order to throw more light upon this subject, the writer is engaged in plotting the daily pendulum movements for both instruments, and the Victoria daily mean temperature is also shown on these annual sheets, and in order to reduce the size of these sheets the time scale used is one millimetre for each day. On these sheets the dates of the lunar phases (new and full), and maximum north and south lunar declinations are entered, also the dates of the deep focus and other destructive earthquakes recorded throughout the world.

From the annual plotted sheets already completed it is noted that the daily pendulum movements are generally of a rhythmic fluctuating nature, and though sudden and pronounced temperature changes do affect these records, they are not the primary cause of these undulations; whereas the times of new and full moon and maximum lunar declinations, have a tendency to occur about the time of the highest and lowest parts of these pendulum undulations.

The deep focus and other destructive earthquakes also occur

[5]"Tilting due to Glacial Melting", *Journal of Geology*, vol. XLI, no. 5, July-August, 1933.

about the same time as the lunar phases and extreme declinations do. Regarding these daily pendulum curves it is clearly noticeable that the correlation is far more marked between the N-S records and the lunar and seismic phenomena than in the case of the E-W pendulum movements.

It is pleasing to note that other studies relating to this subject are being carried out in other parts of the world, and on this continent Dr. Harlan T. Stetson of Harvard has obtained some interesting results.[6]

One is at a loss to understand why these pendulum movements are so pronounced at Victoria as compared with other portions of this continent, unless they may be due to some local unusual geological formation situated below the rock surface here. In connection with this it is interesting to note that from a recent survey made here, it was found that at Victoria a positive gravity anomaly of 0.054 was obtained, which is one of the largest positive anomalies yet discovered on the whole continent.[7]

In conclusion, the writer would suggest that, in order to check these Victoria pendulum observations, other instruments of a similar type be installed at certain sites on the Pacific slope, including Ukiah, California.

In connection with this study the writer gratefully acknowledges valuable information received from the Director of the U.S. Coast and Geodetic Survey, Washington, from Dr. Harlan T. Stetson, Harvard University, and from Dr. W. E. Harper, director of the Dominion Astrophysical Observatory, Victoria.

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[6] *Proceedings of the American Philosophical Society*, dated March, 1936.

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CALENDAR REFORM AND INTERNATIONAL PEACE*

By E. B. Traneus

THE first country to take up direct measures for a reform of the calendar was Switzerland, which thus followed its tradition of working for international co-operation. The Swiss official proposals were initiated in 1913, but the world war disrupted plans for carrying them forward. After the war, however, the Swiss Government persuaded the League of Nations to take up the movement, and the League's offices in Geneva have been the centre of the movement since 1923. After ten years of investigation and promotion, the League has submitted to all nations a draft treaty for the enactment of the reform.

Switzerland meanwhile has carried out an intensive investigation regarding the changes which the introduction of a new calendar would necessitate in the constitution, in civil law and in banking and insurance laws. Switzerland has thus—as often before—proved itself to be a pioneer.

England, however, is the pioneer country in the campaign for a stabilized Easter. The British Parliament has actually passed a bill for a stabilized Easter, and the law may be made effective at any time, under its enacting clause, when other countries are ready to fall in line.

On the question of general calendar reform, the British Government has officially stated that it is favourably disposed and ready to participate in any international arrangement for enactment.

The attitude of France, Germany, Italy and other nations is similar to that of England. In other words, international support is not lacking for adoption of a revised calendar. North and South American nations, without exception, are favourable, and so are Japan and China, in Asia. . . .

To-day's movement for calendar reform is a powerful influence for international peace. In the past, calendrical differences between

*From an article entitled "From a Swedish Viewpoint" in the *Journal of Calendar Reform*", October, 1937.

peoples and races have repeatedly led to riots and even wars. Christendom was agitated for many centuries over the Easter date controversies. Pope Gregory's scientific revision of the calendar caused schisms which are not yet completely healed. Chinese emperors beheaded astronomers for calendrical inaccuracies; London cockneys rioted in 1752 in an effort to make the government give them back their eleven days; Turkey and other Mohammedan countries feared to abandon the moon-year until a very recent date; Russia vainly sought to emphasize and confirm the Bolshevik revolution with revolutionary calendars of various types.

SPACE

Whom the great gods destroy, they first make mad.
The brain reels backward and the senses swoon,
Even to madness, as we muse on thee,
Thou dread companion of immortal time;
For finite reason cannot comprehend
Nor scale the expanses of infinity.

Vastness sublime and the immeasurable depth
Of unplumbed spaces through the unending void
Of trackless distances but hint of thee
And thine omniscient all-compelling power.

Beyond the stars, beyond the bounds of thought,
Beyond the farthest vistas of our dreams,
Forever and forever, on and on
Into the eons of infinity,
Until the faint brain babbles "on and on,"—
And yet we have not started on our way.

Thy breast the bosom is of all the gods.
None lived ere thee, and none shall see thy death.
Time, Time and an eternity of Times
Marked thee beyond the beginning with thy God,
Marshalling the worlds and countermarshalling
The out-wearied playthings of thy changeful moods.

What is there to be done thou hast not done,
Nor yet undone ten thousand million times,
Riding upon the wings of majesty
In chariots of darkness and of light?
Thy power has shaken out the human soul
As dust upon the desert's burning sands.

What art thou in thine unchained essence known?—
A figment of the keen creative brain?
A phantom of imaginative thought
Born of some wayward wandering fantasy,
Or art thou that, where reason overwrought
Makes scientist insane, bewilders sense
And makes concept an universal void.

Give pause, O man! thou frailest of the frail,
Annihilation—

* * * * *

Mayhap in some celestial paradise,
When life's pale shadowy tapers glow anew
In purest light supernal, and the free
Immortal spirit claims her utmost goal,
The heaven-appraising soul may view thy face
And see thee as thou art,—the unending quest—
Eternity in place,—the sovran All.

ALEX. H. SUTHERLAND.

METEOR NEWS

Observations relating to meteors and meteorites are cordially invited.

Binoculars Suitable for Telescopic Meteor Observation

The writer has previously pointed out in these columns the great importance of meteor observations made with some instrumental aid. Visual programmes of meteor observation have been far commoner in the past than telescopic observations and our knowledge of the visual meteors down to magnitudes 4 or 5 is correspondingly more complete. One of the real needs of meteoric astronomy is to have a large number of telescopic meteor observations carried out more or less systematically for several years.

Before one starts on such a programme it is essential that the type of instrument to be used is carefully considered. Unfortunately, the average telescope possessed by the amateur astronomer is not very efficient for meteor observation. This results chiefly from the relatively small field of view found with even the lowest powers of the standard refracting telescope. Among the instruments commercially available it will be found that in general the prism binocular is much better adapted to the observation of meteors. Of course, binoculars are rarely made with objectives larger than two inches in diameter and if it is desired to study meteors fainter than magnitude 10 some adaptation of the refracting telescope must be devised.

A formula designed to serve as a very rough guide to the relative efficiency of instruments for telescopic meteor observation was published in the Journal a few months ago (vol. 31, p. 269, 1937). This defines efficiency as $E=0.6(ad)^2$ where a is the aperture in inches, d the real field in degrees, and it is assumed that the magnification is greater than or equal to $4a$. Of course it must be remembered that this neglects many factors such as the quality of definition over the field, the absorption of lenses and prisms, etc. Also, strictly speaking, we should not compare too closely in this way instruments of various apertures since glasses of smaller aperture, even if very efficient, can never take the place of those with a larger aperture. The mean magnitude of the meteors observed becomes steadily fainter with increasing aperture. For any given aperture and efficiency the

glass with the higher power has advantages since in this case finer details in the meteor's path and train can be noted.

The writer has recently examined the catalogues of some of the leading manufacturers of binoculars. The specifications of the various instruments were considered from the standpoint of usefulness to the meteor observer and the accompanying table lists some of the glasses best suited to this type of work. No attempt has been made to make this complete and it is designed rather to serve as a general guide to the prospective observer of telescopic meteors and to indicate what is currently available in this field.

PRISM BINOCULARS FOR METEOR OBSERVATION

Type	Efficiency	Effective Aperture	Power
Zeiss Deltarem	192	1.6 in	8 x
Busch 9 x 51.5	135	2.0	9
Busch 8 x 42	124	1.7	8
Zeiss Dekarem	124	2.0	10
Busch 7 x 51.5	98	1.8	7
Bausch and Lomb 7 x 50	98	1.8	7
Zeiss Binoctem	98	1.8	7
Busch 6 x 37.5	94	1.5	6
DuMaurier 8 x 34	78	1.3	8
Lemaire 6 x 33.5	76	1.3	6
DuMaurier (monocular)	69	1.3	8

Especial mention should be made of the Zeiss Deltarem. This is a new glass just recently put on the market. The writer was able to test it through the courtesy of the Zeiss agents in Toronto. It has an amazingly wide apparent field of view, over 90 degrees, and should prove extremely efficient in meteor observations. Some distortion can of course be detected at the edges of this large field but this distortion disappears to a great extent if the eye is directed to the edge of the field rather than to the centre.

Most of the binoculars on the above list are fairly expensive. In general, however, monoculars of corresponding type are available at about half the price of the binocular. The DuMaurier 8 x 32 monocular is particularly reasonable in price and has a relatively high

efficiency. The average, 6, 7, or 8 power, 30 to 35-mm. binocular of standard make has an efficiency of about 60 while the small sport and theatre binoculars have efficiencies ranging from 40 down to 20. The average 3 or 4-inch telescope has an efficiency in the neighbourhood of 5 when used with the lowest power. The Zeiss Co., however, manufacture a small 2-inch telescope, "Aseros", with a variable power from 4 to 20 and this, when used at 8 x, has an efficiency of 105.

It is of interest in this connection to note the types of instruments used in two recent programmes of telescopic meteor observation. On the Harvard Meteor Expedition to Arizona a 4-inch refractor of 17 x giving a field 3.65 degrees in diameter was used (H.C. 390). The efficiency of this instrument, on the above scale, is 124. Dr. Astapowitsch, in his telescopic meteor observations in Russia, used a number of instruments. One of these was a Zeiss 5-inch comet seeker with efficiency 174 and another a Reinf and Hert 6-inch comet seeker with efficiency 103. He also used Zeiss 6 x 30 binoculars with efficiency 54 and other binoculars of somewhat lower efficiency.

The visual observer of meteors should always, whenever possible, keep an efficient pair of binoculars handy while he is observing. Every persistent train lasting longer than two or three seconds should be observed with these. Eppe Loreta, in Bologna, has demonstrated the valuable work that can be accomplished in this way. The persistent train of a meteor always remains visible in the glasses longer than it does to the naked eye and with 6 or 8 power fine details and changes of form are more easily seen.

Meteor Observations made in Orillia, 1937

The valuable observations of meteors, made by Mr. Jack Grant in Orillia at the time of the Perseid shower in 1937, have already been reported. In addition to these Mr. Grant made a series of visual and photographic observations of meteors during the summer and fall of 1937. These are summarized in the table. The F/1.9, 25-mm. lens was used consistently and, for the Orionid and Leonid observations, two other cameras of speeds F/6.3 and F/8 were also used. Very little clear weather was experienced at the time of either of these showers. One Orionid meteor of magnitude 0 was photo-

METEOR OBSERVATIONS, ORILLIA, 1937

Date	Approximate E.S.T.	Total Exposure Time	Meteors Photographed	Total Visual Observation	Meteors Observed	Weather Factor
May 10-11	10.00-12.00	1.6 hrs.	..	49 m.	10	10
June 14-15	11.40- 3.10	2.7	..	61	9	9
June 15-16	12.30- 3.20	2.3	..	60	2	10
July 5-6	10.50- 1.00	1.8	..	28	4	7
July 27-28	2.30- 3.40	0.8	..	11	3	7
July 28-29	1.00- 3.40	1.7	..	27	1	4
Aug. 5-6		1.3	..	..	..	..
Oct. 16-17	4.00- 5.20	2.4	..	19	6	10
Oct. 21-22	2.10- 3.10	1.2	1	16	2	4
Nov. 15-16	5.40- 6.00	0.7	..	..	1	5

graphed with the F/6.3 lens. The magnitude distribution of the meteors visually observed is given below.

Mag.	0	1	2	3	4	5
Meteors	2	8	10	9	7	4

During 1937 Mr. Grant has been the most consistent meteor observer in Canada and his work is of very real value.

P. M. M.

NOTES AND QUERIES

Communications are invited, especially from amateurs. The Editor will try to secure answers to queries.

Atlas of Nova Herculis 1934

Under the auspices of the International Astronomical Union an atlas of the spectra of Nova Herculis 1934 is being prepared at the Solar Physics Observatory, Cambridge, England. Spectrograms for almost every day from the initial outburst are available, and the series will be printed on sixteen stiff cards. The cost will likely be £1, if sufficient support is forthcoming. Further inquiries and subscriptions should be directed to Prof. F. J. M. Stratton, Director of the Solar Physics Observatory and chairman of the committee in charge.

A Lunar Eclipse in Turkey

The date is December 8, 1927; the place is Kaesarea, near the centre of Turkey; the writer is Harold Armstrong in "Turkey and Syria Reborn", p. 183, (1930). The author, a Turkish-speaking Englishman, was in Turkey on post-war business. He says:

I had eaten my dinner in the hotel and was crouching beside the wood stove for warmth, when there broke out suddenly the sound of heavy rifle-fire. The Bosnak had his revolver ready in a minute, and was watching at the window. The fat merchant became a jelly and called loudly on "Allah". Some said a revolution, others a massacre, others brigands, others that the Kurds had come raiding. Each spoke in the terms of things to which he had been accustomed in this fierce country.

We streamed out into the street. It was the night of the full moon, and a total eclipse was beginning. From every side came the sound of rifle and revolver shots and the whistle of bullets in the frozen, crisp air. The gendarmes in the post across the square were freely loosing-off Government ammunition.

"What is it?" I asked tremulously.

"They are firing," said one, "to keep the Bear from eating the Moon. See, he has begun already", as the earth's shadow was half across the moon.

The eclipse over, the firing died down. The rest returned to the hotel, and I was left alone.

A further quotation, unrelated to astronomy, from the same book (p. 198) may be found interesting at the present time:

The Government in form was parliamentary, but it was an empty form. There was no opposition, and all members were the nominees of Mustapha Kemal, but the form was being kept deliberately as an education and to be

used by the next generation, who would have learned their powers and responsibilities. And herein Mustapha Kemal may have made a cardinal error, for just as Bolshevism has succeeded nowhere outside Russia, and Fascism nowhere outside Italy, so the parliamentary system seems to be essentially Anglo-Saxon, and to fail with other races.

Scientific Research Fifty Years Ago

The condition of scientific research in the United States and Canada fifty years ago as compared with the present time is referred to in a biographical sketch of Edward Leamington Nichols by Ernest Merritt in *Science* for November 26, 1937. Nichols was born of American parents at Leamington, England, September 14, 1854, and died November 19, 1937. He graduated from Cornell in 1875, and obtained the Ph.D. degree at Goettingen in 1879. He was head of the Physics Department at Cornell from 1887 to 1919, when he retired. Professor Merritt says:

> In these days of rapid progress and widespread interest in all branches of science it is hard to realize how insignificant was the contribution of this country to the physical sciences sixty years ago. In only a few universities was scientific investigation actually under way, or even regarded as a proper function of the college teacher. Industrial research laboratories were not even mentioned as a possibility. Nichols contributed more than any other physicist of his generation to change this situation, and he was almost the last remaining member of that small group of men who kept physics alive in this country during the last two decades of the last century and prepared the way for the remarkable progress of the last twenty years. . . . He was one of the most active of the small group who organized the American Physical Society in 1899. The *Physical Review*, founded by Nichols in 1893 and conducted for the first twenty years under his editorship, was the first journal of physics in this country and was an important factor in stimulating scientific activity.

The present writer has been a subscriber to the *Physical Review* from its inception and a member of the American Physical Society from the beginning. He also visited Professor Nichols in his laboratory at Cornell in 1893. Before the *Physical Review* was founded some researches in physics were published in the *American Journal of Science*, which has had an honourable career since 1819. The *Physical Review* at the beginning was finely printed on superior paper with broad margins, and a well-known American physicist was heard to compare it to a small clear stream flowing between wide banks. The mighty river of research in various branches of physics which

is sent forth by the American Institute of Physics shows well the change in fifty years. One might also remark on the immense output of physical apparatus in the United States now. Fifty years ago it was practically all imported from Europe.

In chemistry the record is even more notable than in physics. In chemical theory there have been remarkable advances and young scientists do not have to go to Europe for graduate studies, although a year or more spent abroad will always be valuable. The practical applications of chemical research have been numerous and outstanding and have altered enormously our manner of living.

The growth in astronomy has been quite noteworthy in the United States, and in Canada, relatively to population, it has expanded in even a greater degree. Various observatories in the United States had their own publications for many years, but the *Astrophysical Journal*, begun in 1895, has led the way in the physical side of astronomy. This is truly the age of science.

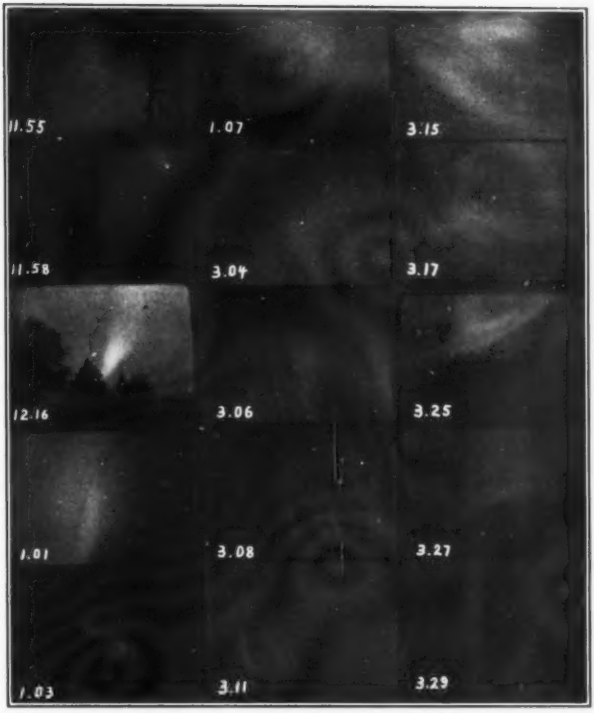
Mathematicians and their Work

Reference has been made in a previous issue to the book "Men of Mathematics" by Eric Temple Bell. It was published in New York early in 1937 and later was brought out in London. The author, who is professor of mathematics in the California Institute of Technology, sketches in a vivacious way the lives of some thirty-five of the world's greatest mathematicians and attempts to interpret their achievements to the educated layman. Any person who has a liking for biography and a taste for mathematics will find the book full of entertainment and instruction.

A few extracts from the volume may be of interest to the readers of this column. The first quotation refers to Archimedes, the greatest of the ancient scientists, and the rest deal with modern giants of the mathematical world.

Ancient and Modern.—Archimedes (287?-212 B.C.), the greatest intellect of antiquity, is modern to the core. He and Newton would have understood one another perfectly, and it is just possible that Archimedes, could he come to life long enough to take a post-graduate course in mathematics and physics, would understand Einstein, Bohr, Heisenberg, and Dirac better than they understand themselves. Of all the ancients Archimedes is the one who habitually thought with the unfettered freedom that the greater mathematicians

PLATE I



Auroral Photographs taken by Jack Grant, August 1-2, 1937.
The numbers are the Eastern Standard Time of the exposures.

permit themselves to-day with all the hard-won gains of twenty-five centuries to smooth their way, for he alone of all the Greeks had sufficient stature and strength to stride clear over the obstacles thrown in the path of mathematical progress by frightened geometers who listened to the philosophers. (p. 19).

Mathematics and Music.—As mathematicians often have a liking for music it is of interest to note here that Weierstrass (1815-1897), broad as he was, could not tolerate music in any form. It meant nothing to him and he did not pretend that it did. When he had become a success his solicitous sisters tried to get him to take music lessons to make him more conventional socially, but after a half-hearted lesson or two he abandoned the distasteful project. Concerts bored him and grand opera put him to sleep—when they could drag him out to either. (p. 410).

Mathematics and Perfection.—After all, why should mathematicians, who are human beings like the rest of us, always be so pedantically exact and so inhumanly perfect? As Weierstrass said, "It is true that a mathematician who is not also something of a poet will never be a perfect mathematician." That is the answer: a perfect mathematician, by the very fact of his poetic perfection, would be a mathematical impossibility. (p. 432).

Irish Mathematician and Scottish Philosopher.—Sir William Rowan Hamilton (1805-1865) was the greatest man of science Ireland has produced. He was a prodigy for all kinds of learning and became a great creative mathematician. At twenty-two, while still an undergraduate, he was elected professor of astronomy at Trinity College, Dublin, over the heads of several distinguished astronomers who were candidates for the position. On the other hand, Sir William Hamilton (1788-1856) was a Scottish philosopher. Mathematicians speak of him as the *other* Hamilton, and his attack on mathematics is one of the most famous in history. Some of his hottest shots are the following (p. 440):

Mathematics freeze and parch the mind.

An excessive study of mathematics absolutely incapacitates the mind for those intellectual energies which philosophy and life require.

Mathematics cannot conduce to logical habits at all.

In mathematics dullness is thus elevated into talent, and talent degraded into incapacity.

Mathematics may distort but can never rectify the mind.

The philosopher certainly did not speak from any deep knowledge of mathematics.

Psychology of Mathematical Creativeness.—Henry Poincaré (1854-1912) was the last man to take practically the whole of

mathematics, pure and applied, as his province. Also, he had a remarkable insight into the philosophy of his subject and a superior gift of clear exposition. Further, he endeavoured to investigate the psychology of mathematical creativeness and described some of his own experiences. The author of the book remarks (p. 530):

> All "explanations" of creativeness that fail to provide a recipe whereby a gifted human being can create are open to suspicion. Poincaré's excursion into practical psychology, like some others in the same direction, failed to bring back the Golden Fleece, but it did at least suggest that such a thing is not wholly mythical and may some day be found when human beings grow intelligent enough to understand their own bodies.
>
> One of Poincaré's passions was symphonic music (p. 553).

Fundamentalists and Modernists.—The last chapter of the book is devoted to Georg Cantor (1845-1918) and the harsh attacks on him by Kronecker (1823-1891). Indeed one is reminded of the bitter controversy between "fundamentalists" and "modernists" in the religious world. The author remarks (p. 563):

> It is sometimes imagined by outsiders that originality is always assured of a cordial welcome in science. The history of mathematics contradicts this happy fantasy: the way of the transgressor in a well-established science is likely to be as hard as it is in any . . field of human conservatism, even when the transgresor is admitted to have found something valuable by overstepping the narrow bounds of bigoted orthodoxy.

The great trouble arises over the attempts to define such concepts as *real number, cardinal number, continuity, limit* and *infinity* in such a way that they may be used in a precise and consistent manner in mathematics. The following quotation is illuminating (p. 572):

> At this point we may note two modes of expression which recur constantly in nearly all mathematical exposition. The reader perhaps has been irritated by the repetitious use of phrases such as "we can find a whole number greater than 2", or "we can choose a number less than n and greater than $n-2$". The choice of such phraseology is not merely stereotyped pedantry. There is a reason for its use, and careful writers mean exactly what they say when they assert that "we can find, etc.". They mean that *they can do what they say.*
>
> In sharp distinction to this is the other phrase which is reiterated over and over again in mathematical writing: "There exists". For example, some would say "there exists a whole number greater than 2", or "there exists a number less than n and greater than $n-2$". The use of such phraseology definitely commits its user to the creed which Kronecker held to be untenable, *unless,* of course, the "existence" is proved by a "construction". . . . .

These two ways of speaking divide mathematcians into two types: the "we can" men believe (possibly subconsciously) that mathematics is a purely human invention; the "there exists" men believe that mathematics has an extra-human "existence" of its own, and that "we" merely come upon the "eternal truths" of mathematics in our journey through life, in much the same way that a man taking a walk in a city comes across a number of streets with whose planning he had nothing whatever to do.

Theologians are "exist" men; cautious skeptics, for the most part, "we" men. "There exist an infinity of even numbers, or of primes", say the advocates of extra-human "existence"; "produce them", say Kronecker and the "we" men.

The layman may well ask, what is the conclusion of the whole matter? Will the matter ever be settled?

C. A. C.

A Brilliant Auroral Display, Aug. 1-2, 1937

A brilliant auroral display was seen in Ontario on the night of Aug. 1-2. At 11.34 p.m. Dr. J. F. Heard at the Dunlap Observatory noted a bright band about a degree wide and 120 degrees long which lay in an east-west direction through α Peg. and Lyra to 5 degrees south of Arcturus. This moved south and disappeared about 11.40 p.m. It seems to have been similar to the band of Apr. 30 reported in the Journal for July-Aug., 1937.

Between 11.40 p.m. and 4.00 a.m. on the night of Aug. 1-2, Mr. Jack Grant in Orillia made a series of exposures on the auroral streamers with excellent results. He used a 16-mm. movie camera with a lens of focal length 25 mm. and speed F/1.9. The camera was loaded with Eastman "Super X Pan" film. A number of Mr. Grant's photographs are reproduced in the accompanying Plate I and well illustrate an interesting phase of astronomical photography which can be carried out with small fast lenses. The exposures for the photographs taken before 3.00 a.m. varied between one and two minutes. Those taken after this time were exposed from 10 to 20 seconds.

Mr. Grant, in his visual observation of the display, noted that from shortly after midnight until dawn the auroral rays came to a focus overhead at a point which remained approximately fixed, roughly 20 degrees SE of the zenith. Several times rays, brighter

and greener than usual, were observed near the horizon, and these drifted slowly southward. Examples of these are shown in the photographs taken at 12.16 and 1.03. In the first case the southward drift was 3 degrees per minute and in the second, half this value. Change of position and form can be noted in the series of photographs taken just after 3.00 a.m. Vega is the bright star seen here. Other stars may be recognized as faint dots on some of the photographs. The bowl of the Big Dipper appears on the first exposure and Capella on the second, third, fifth, and sixth. The star near the centre of the last three reproduced is α And. Photographs such as these, made simultaneously from opposite ends of a base line, are the source of all our reliable knowledge of auroral heights. Most of such work in the past has been carried out by Prof. Störmer in Norway.

P. M. M.

MEETINGS OF THE SOCIETY

AT TORONTO

November 23, 1937.—The regular meeting of the Toronto Centre was held in Room 43 of the McLennan Laboratory, University of Toronto, on Tuesday, November 23, 1937, Mr. E. J. A. Kennedy, Chairman, presiding.

The following nominees were elected to membership on the motion of Messrs. Brown and Collins:—

Miss Elsie Greenlow Banks, 18 Rowanwood Ave., Toronto.

Mrs. C. P. Smith, 72 Lynwood Ave., Toronto.

Mr. G. L. Arbuckle, 49 Gloucester St., Toronto.

Mr. R. H. Combs then showed us two reels of motion pictures. The first taken by himself, was in colour and included beautiful and interesting scenes in various parts of North America,—the Columbia River Drive, Oregon, the new San Francisco-Oakland Bridge, the Great Salt Lake, Utah, Rocky Mountains in Canada, and some sunset views. The second reel gave the 1932 solar eclipse as taken by the McMath-Hulbert observatory expedition.

Mr. J. R. Collins, then showed us pictures of some observatories in the United States which he visted this summer. These included the Darling Observatory at Duluth, the Warner-Swasey Observatory in Cleveland, Yerkes Observatory and Adler Planetarium at Chicago, and the McMath-Hulbert Observatory near Pontiac, Michigan. Time did not permit Mr. Collins to introduce us to all the interesting places he visited but we look forward to this pleasure in the near future.

Dr. Heard continued his lectures on the elements of Astronomy by explaining the meaning and inter-relation of the terms apparent size, true size, distance, geocentric parallax, horizontal parallax, and trigonometric parallax.

December 7, 1937.—The regular meeting of the Toronto Centre was held in the McLennan Laboratory, University of Toronto, on Tuesday, December 7, 1937, with E. J. A. Kennedy in the chair.

The first speaker of the evening was Mr. P. D. McTaggart-Cowan of the Meteorological Service of Canada, who spoke on "Forecasting Weather For Transatlantic Aircraft". Mr. McTaggart-Cowan is just returned from Botwood, Newfoundland, where he spent the summer helping to forecast the weather for the practice flights. The first part of his address included the Shell Oil Co.'s film, "Wings Over the Atlantic", which showed the construction going on, at Newfoundland Airport, Gander Lake, and of the simultaneous flights made this summer by the Imperial Airways, Caledonia, from Foynes, Ireland, westward, and the Pan American Airlines' Clipper Ship III, from Botwood eastward. Then with lantern slides, Mr. McTaggart-Cowan showed us samples of the consecutive weather maps made each 36 hours

before each flight, and explained how these were used to forecast a complete set of weather conditions across the Atlantic.

Following a short discussion, Mr. Collins moved a vote of thanks to the speaker.

Dr. Heard continued his course in Astronomy by describing "The Mechanical Aspect of the Solar System." This included a brief outline of the geometry of conic sections, the types of orbits associated with planets, comets, asteroids and meteors, and the elements of planetary orbits.

This being the last meeting of the calendar year, the secretary, Mr. Harvey, read a report summarizing the meetings during the past year. The nominating committee, Dr. R. K. Young, Mr. J. H. Horning, and Mr. J. R. Collins, moved that the officers remain unchanged for the ensuing year. However, Miss Patterson, Recorder, finds herself unable to continue in that capacity due to the pressure of academic duties. The committee nominated Dr. Best as Recorder. The members present were unanimous in their approval of the committee's nominations. The meeting then adjourned.

F. SHIRLEY PATTERSON, *Recorder.*

AT WINNIPEG

November 10, 1937.—The regular meeting was held on November 10 in Theatre E, Broadway. President Darracott indicated that the prospects of the Society continued healthy and called on Mr. Colquette first for running comment on extra-terrestrial affairs. The successes attained by various eclipse parties came in for attention, particularly the air-photographs which had given a new and obviously more accurate conception of the corona.

Mr. A. V. Piggott's talk on Comets and Meteors followed, revealing a bias against the angel-or-devil concepts that had one time prevailed. It was certainly a surprise to find the eminent name of Tycho Brahe associated with weird and fantastic theories of comets. We gathered that while iron and nickel were found in the surviving parts of meteors, complex hydro-carbons had been associated with such aggregations as showed millions of miles of Coma when in the neighbourhood of the sun. Apparently, however, the derivation of brain and conscience, memory, imagination and hope from these hydro-carbons has not yet been definitely proved. Mr. Piggott is always interesting. The attendance, owing to other attractions, was somewhat smaller than usual.

G. P. MORSE, *Secretary.*

AT VANCOUVER

October 12, 1937.—The 49th regular meeting of the Centre was held in the Science Bldg., U.B.C., on October 12, with Mr. H. P. Newton presiding. Attention was drawn to the "Sky" bulletin of the Hayden Planetarium in New York.

Inaugurating a new feature of a secondary topic for each meeting, Mr. C.

A. McDonald gave a brief outline on "Evolution of the Solar System", discussing the "Tidal" theory as the one having been most generally accepted. Aiming at continuity in this "Half-hour Series" of talks, the elements of the solar system will be dealt with at the other meetings of the session.

The main topic for the evening was entitled "Exploding Stars" and was given by Dr. W. E. Harper, Director of the Dominion Astrophysical Observatory at Victoria. The speaker briefly touched upon the nature of the bodies that blow up by showing slides of the sun, a typical star, and giving some facts as to its size, mass, density, temperature, etc. Passing briefly over causes of variation in a star's light he came to the class under consideration, where a star for some reason starts to expand and literally blows up in a great outburst of light. These are known as new or temporary stars, or novae.

Reference was made to legendary novae before dealing with those observed in modern times since the appearance of the brilliant new star in Cassiopeia in 1572. The present century has been prolific in new stars, already half a dozen bright ones having been seen. Considering faint photographic specimens, about twenty per year may be expected.

Novae are found most frequently in the plane of the Milky Way where nebulous material abounds and this is true of other spiral nebulae where the yearly number of new stars is of the same order as in our own stellar system. Their discovery and apparent faintness at maximum suggested the great distance of the spirals in which they are found.

Examples of the light curves of several novae were shown. Always there is a very rapid rise to maximum and a slow and sometimes fitful decrease. A 10,000-fold increase in luminosity in two days is not uncommon. Amateurs are doing good work observing the light variations, and the light curves are supplementing other data in testing theories as to their nature.

Chief reliance is placed, however, upon the spectrum which shows remarkable changes as the star passes through succeeding stages. The bright nova which appeared in Lacerta in June, 1936, was extensively studied at Victoria and the facts thus learned were presented through the aid of slides. The star, originally similar to our sun, started to expand and at maximum had a diameter about 210 times that of our sun. While the shells thrown off kept on expanding at 2500 km/sec the nucleus or photosphere started to shrink and in six weeks had a diameter only 3 times that of the sun. At that time, fully as much light came from the expanding shells as from the photosphere.

Within the past couple of years a new class, designated super-novae, has come to our notice. These have a luminosity one thousand or more times that of the ordinary novae and are of the same order of brightness as the distant spiral nebulae in which they originate. Two were discovered in September at Mount Wilson and spectra obtained at Victoria were shown bearing out the idea that enormous velocities of expansion are the cause of these. Reference was made to the suggestion that these great outbursts are the source of the highly penetrating cosmic rays.

November 9, 1937.—The 50th regular meeting was held at the University of British Columbia, on Tuesday, November 9, Mr. H. P. Newton presiding.

Mr. D. L. Shaw took the half-hour topic "The Earth" and briefly discussed modern theories as to its structure, composition, temperature and age.

Dean D. Buchanan of the University of British Columbia, called upon by the president to speak on "The Red Shift of the Receding Nebulae", first introduced Dr. Anderson of the University Physics Department who gave a demonstration in spectroscopy and explained the significance of spectrum analysis particularly in relation to velocities in the line of sight.

Dean Buchanan began his subject with illustrations of relative motion by means of blackboard sketches. Investigations of distant nebulae reveal a progressive increase in velocities of recession with increasing distance of the nebulae. This increase amounts to 340 miles per second with every 3.2 million light-years. Instances were given of velocities to 24,000 miles per second and a distance was estimated at which the velocity would be greater than that of light where difficulty with the Relativity Theory would appear. After suitable analogies in 1, 2 and 3 dimensions, the speaker touched on the four-dimensional nature and curvature of time-space, by which the finite but unbounded universe of Einstein is rendered somewhat less obscure. Within such a universe, radiation may return to a starting point. The radius and, therefrom, the time required may be calculated. Other points in Relativity and the proofs that have commanded acceptance of the theory were outlined briefly and the possibility that the Einstein universe is unstable was discussed.

The Dean's address was much appreciated, being an agreeable blend of fact, theory and humour, presented with easy informality. In discussion, Mr. Frostrup thought that the progressive increase in velocity with distance would imply that our galaxy is at the centre of the universe, an unlikely possibility.

J. TEASDALE, *Secretary.*

The Royal Astronomical Society of Canada

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